AD

AF EOAR GRANT ~~61-67~~ 62-15

TR

October 1962

TECHNICAL REPORT

HIGH ENERGY PHYSICS PROPERTIES OF ANTIPROTONS, K MESONS, HYPERONS, and PIONS

A. G. Ekspong

Institute of Physics
University of Stockholm
Stockholm, Sweden

The research reported in this document has been sponsored by, or in part by, the Air Force Office of Scientific Research, OAR, through the European Office, Aerospace Research, UNITED STATES AIR FORCE.

AD

AF EOAR GRANT ~~67~~ 62-15

TR

31 October 1962

TECHNICAL REPORT

HIGH ENERGY PHYSICS

PROPERTIES OF ANTIPROTONS, K MESONS, HYPERONS, and PIONS

A.G. Ekspong

Institute of Physics
University of Stockholm
Stockholm, Sweden

The research reported in this document has been sponsored by, or in part by, the Air Office of Scientific Research, OAR, through the European Office, Aerospace Research, UNITED STATES AIR FORCE.

ABSTRACT

In an investigation of 537 interaction stars in nuclear emulsion exposed to a beam of 2000 MeV/c antiprotons, mixed with some pions and muons, about 215 stars were estimated being due to antiprotons, the rest due to pions. The antiproton mean free path at this momentum was found to be 26 ± 5 cm. The average number of charged pions outside the capturing nucleus is $2.64 {}^{+0.25}_{-0.33}$ for antiproton stars; the average pion energy is 430 ± 50 MeV including the rest mass of 140 MeV. The average pion multiplicity in the annihilation process is found to be $5.0 {}^{+0.5}_{-0.6}$. Detailed calculations of pion interactions inside the nucleus were performed. No antisigma hyperon was found.

In another investigation of 2000 MeV/c pions, 281 interactions with emulsion nuclei were studied. The mean number of emitted charged pions is 1.21 ± 0.08 per star; the fraction of stars with charged secondary pions is 75 ± 3 per cent. The results agree well with the predictions of the cascade calculations of Metropolis et.al., but are in disagreement with the experimental results by Crew and Hill.

A discovery of a line was made in the momentum spectrum of the $\Sigma\pi$ system emitted from nuclei when negative K mesons are absorbed at rest. The line was unexpectedly narrow, contained in a band of width $\pm$ 10 MeV/c. Its position was determined to be 171 ± 2 MeV/c. By a careful study of the short recoil tracks from the residual nucleus and also by other means it was concluded that the line should be interpreted as being caused by a reaction where a new particle, Y^*, is emitted. The reaction which fits the observations is

$$K^- + {}^{12}C \rightarrow Y^* + {}^{11}B$$

It is concluded that the mass of Y^* is 1404.7 ± 0.4 MeV. This is close to the value for Y_0^* (about 1405 MeV). The mass width of our Y^* is unexpectedly small, being found less than 1.4 MeV, whereas for Y_0^* a width of 50 MeV has been reported.

The investigation of the pion-electron scattering cross section with 16 GeV/c pions incident on a hydrogen bubble chamber has been concluded. In a fiducial volume of chamber about 1000 scattering events has

been analyzed in the electron energy region from 30 MeV up to the maximum possible, viz. 7300 MeV. The differential and integrated cross sections agree well with those predicted by the Bhabha formula for a point charge pion over most of the energy region investigated. A tendency to lower values of the cross sections in the region of high momentum transfers may be due to an extended structure of the pion. However, the statiscal errors are such as not to rule out a zero radius of the pion. In order to increase the statistics, a joint paper is under preparation with addition of events investigated in Aachen (Deutschman and Fischer).

The study of interactions of antiprotons of 3.6 GeV/c momentum with protons in a large hydrogen bubble chamber is under way. Emphasis is laid on the study of pion production, multiplicity and angular distribution as well as production of pion resonances. Also the production and subsequent annihilation of antineutrons is taken up. These investigations are now in a preliminary stage, where scanning has advanced well.

Contents

The report is based on work carried out by the following group of people:

J.Allan	Å.Frisk
P.J.Carlson	L.E.Lundh
O.Danielsson	T.Ulhede
A.G.Ekspong	B.E.Ronne
	P.Sällström

REPORT

1 and 2: HIGH ENERGY ANTIPROTONS AND PIONS

The research reported in the two papers on 1.3 GeV antiprotons and on 2 GeV pions is completed. As emulsion detectors present difficulties due to cascades insides the nuclei it seems more profitable to continue the research at higher energies by using hydrogen bubble chambers. Such work has already started at the institute with antiprotons of 3.6 GeV/c momentum, obtained in the Saclay bubble chamber with a beam of separated antiprotons at CERN.

3. Research on Y^* produced by negative K Mesons

(see paper on p. 5)

Production of Σ Hyperon Pion Pairs.

by

Å. Frisk and A.G. Ekspong

Institute of Physics

University of Stockholm

With a view to detect effects due to the Y^* particles, we have recently made experiments in which negative K mesons were arrested in photographic emulsions. When the experiment was begun, only two states, Y_0^* and Y_1^*, where known,[1,2] with masses near 1405 MeV and 1385 MeV, respectively. Previous measurements on both these states have indicated mass distributions with widths of some tens of MeV, [3,4,5,6] and only the first, Y_0^*, decays into a pair of charged particles Σ and π. Much to our surprise, our results appear to indicate the existence of a Y^* particle with a mass of 1405 MeV but with a width at least two orders of magnitude less than the values previously reported; viz $\lesssim 1$ MeV.

A well defined, separated beam of negative K mesons from the Lawrence Radiation Laboratory Bevatron [7] was moderated by an absorber so that the K mesons stopped after traversing a few centimetres of nuclear emulsion. The stack of emulsions serves as both target and detector. The present report is based on information obtained from a first sample of about 6000 K mesons which interacted at rest with emulsion nuclei (H, C, N, O, Ag, and Br).

The selected sample consists of those events from which the only charged particles emitted are a Σ hyperon and a pion except for a possible nuclear recoil of short range ($<$ 5 μm) and one or more Auger electrons. This selection was made in order to enrich the sample with events in which the hyperon and the pion have not interacted inelastically with the residual nucleus. In order to obtain a sample of rather well measured events, a geometrical criterion was imposed restricting the dip-angle of the pion track to less than 30° with respect to the plane of the unprocessed emulsion. No bias is thereby introduced; the selection merely reduces the size of the final sample to about 2 % of the stopped K mesons.

The momenta of the Σ hyperon and of the pion from each event were measured together with the angle between them. The momentum was determined by range measurements whenever possible; and otherwise by grain counting (of 1000 grains) or gap counting. The information obtained in this way was used to compute the momentum of the $\Sigma\pi$ system, $\bar{p} = \bar{p}_{\Sigma} + \bar{p}_{\pi}$, and the individual energies E_{Σ} and E_{π}. In what follows $\bar{p}$ denotes the recoil momentum. The typical standard error in this quantity in 80 % of the sample is about 5 MeV/c; and in the total energy ($E_{\Sigma} + E_{\pi}$), about 6 MeV. An attempt was made to follow the method suggested by G. and S. Goldhaber and first applied by Eisenberg et. al[8] in which the distribution of the invariant mass of the $\Sigma\pi$ system is studied. As was pointed out by Burhop[9], however, the interpretation in terms of Y^{*} is difficult and uncertain. This approach was later abandoned after the discovery of a line in the distribution of the recoil momentum, $\bar{p}$, as reported by one of us (A.F.) at the International Conference

on High Energy Physics at CERN (1962).

An unexpected, sharp line in the recoil momentum spectrum at a momentum of 170 MeV/c is clearly visible in Fig. 1. Part of the data in Fig. 1. (49 events) has already been published by one of us together with S.Nilsson[10]. In assembling the material, events which could be interpreted as due to capture by hydrogen have been excluded. These events have a recoil momentum equal to zero within the errors of measurement. The appearance of the spectrum in Fig. 1 suggests that it corresponds to a smooth background distribution with a sharp line at 170 MeV/c. The background may consist of many unresolved lines or of a smooth statistical distribution. Here we shall not be concerned with the nature of the background, but shall concentrate our attention on the line. The level of statistical significance of the peak at 170 MeV/c in Fig. 1 may be inferred from the fact that the peak contains 32 events per 20 MeV/c whereas the background contains about 13 events per 20 MeV/c in the neighbourhood of the line. The peak thus rises above the background by about 5 standard deviations, assuming a Poisson distribution. The probability that we are dealing with a chance fluctuation in a smooth background distribution is so small that we find it reasonable to assume that the line is real. We have not been able to find any reason for a systematic effect in the sampling or in the measurements which could produce such a line. Therefore, we feel justified in interpreting the line as being caused by a definite physical process.

The characteristic of a two-body process at rest is that each component carries off the same constant momentum if the masses of the two components are approximately constant, and the point of interest

in the present result is the constancy in the momentum of the $\Sigma\pi$ system indicating the possibility that a Y^* with well defined mass is emitted. We will, however, for the moment direct our attention to the nature of the recoiling system. If the line is due to K^- capture by heavy emulsion nuclei (Ag and Br), the track of the recoiling nucleus will be too short to be distinguished. On the other hand, if the capturing nucleus is one of the light nuclei (C, N, and O), a visible recoil track should appear. At 170 MeV/c momentum, the mean observed range is expected to be 2.5, 2.0, and 1.8 μm for captures by carbon, nitrogen and oxygen, respectively[11]. If the line results from captures by both heavy and light nuclei, it should appear both in samples of events with no visible recoils, and in those with recoils. Measurements on recoil tracks of the expected short range present, however, some difficulties. A recoil track may in some cases be obscured by one of the other tracks (due to K, Σ, or π); by the center of the star if the recoil is more or less parallel to the line of sight; or by an Auger electron. It is also sometimes difficult to distinguish tracks due to slow Auger electrons from those due to recoil nuclei, especially for ranges below about 1.5 μm.

For these reasons we first selected a sample of events where no recoil is visible and no Auger electron. The events in this class are therefore clear of secondary grains at the star center, or they contain at most a single larger grain (blob). The recoil momentum distribution in this sample is shown in Fig. 2. No line at 170 MeV/c is present. By separating these events the sample which remains is relatively rich in events with a recoil track. The corresponding momentum spectrum is shown in Fig. 3 where the line is even more pronounced than in Fig. 1. The

background level in the vicinity of the line is reduced to half intensity whereas the strength of the line is unaffected. The statistical significance of the line in this sample is very great; the peak at 170 MeV/c rises above the background level by about 7 standard deviations. Finally, in 11 events a clear, straight and unobscured recoil track was visible with no accompanying tracks due to Auger electrons. In all but 3 of these events the recoil momentum was 170 MeV/c within errors (2 standard deviations) as is seen from Fig. 4. Here practically all the background has disappeared. The strength of the line is compatible with full strength, which is 19 ± 6 events in Figs. 1 and 3, if one keeps in mind that obscured recoils are not included, even if there is some evidence for their presence. It should be mentioned that in the last sample (Fig. 4) an event was accepted only if the recoil was in a direction opposite to the computed direction of the momentum of the $\Sigma\pi$ system, within $\pm 20^{\circ}$ in plane angle, and rather less precisely in dip angle which is more difficult to define. Most events with a clear recoil fulfilled this direction criteron which is necessary but not sufficient to balance momentum. The ranges of the recoils (after correction for dip) in the 170 MeV/c peak in Fig. 4 is between 1.8 and 3.4 μm with a mean of 2.8 $\pm$ 0.2 μm. Momentum is balanced if we assume most of the events to be due to capture by carbon, with boron recoiling.

In attempting to interpret the results, we have found no valid reason to invoke peculiarities in nuclear structure. It is expected theoretically, and demonstrated experimentally that the internal momentum distribution of the protons bound in light nuclei is a smooth one[12]. We are led to regard the following reactions as mainly responsible for the momentum line:

$$K^- + {}^{12}C \rightarrow Y^* + {}^{11}B \qquad (1)$$

$$\hookrightarrow \Sigma^{\pm} + \pi^{\mp} \qquad (2)$$

Reaction (1) is a two-body process capable of producing the observed line at 171 MeV/c if the mass of Y^* is close to 1405 MeV. In what follows we shall assume the interpretation in terms of Y^* to be valid.

The most unexpected and remarkable feature of the results is the sharpness of the observed momentum line. The Q-value of reaction (1) is very sensitive to variations in the mass of Y^*. At the observed average momentum of 171 MeV/c, Q is only 11.9 MeV. It follows that a Y^* width of more than 12 MeV should spread out the momentum line over the range from 0 to 240 MeV/c or more. No sharp line is then to be expected. Nor can arguments based on the limited phase space be invoked to reconcile the narrow momentum line with a large Y^* width because phase space does not vary much in the narrow region of our line. The relation between variations in the mass of Y^* (δm) and variations in the recoil momentum (δp) is for a two-body reaction like (1) given to a good approximation by the relation: $\delta m = - v \cdot \delta p$
where v is the relative velocity between Y^* and the residual nucleus. The great sensitivity of the present experiment lies in the low velocity of the produced Y^* ($\beta = \frac{v}{c} \simeq \frac{1}{7}$ at the line position). On the basis of our observations we conclude, since $\delta p = \pm 5$ MeV/c, that the range of variation in mass of the Y^* is less than $\pm$ 0.7 MeV. As the observed line width is consistent with our experimental resolution, the width (Γ) of the Y^* mass distribution must be less than 1.4 MeV. It should be noted that this result is not dependent on the assumption that the reactions occur in carbon. The same result follows quite generally for any assumed cap-

turing nucleus. The lifetime of the Y^* is then rather long, compared to 10^{-23} sec viz. $> 5 \cdot 10^{-22}$ sec. One possible explanation of such a relatively long lifetime would be a high spin for Y^*, $\geqslant \frac{3}{2}$, and a small interaction volume.

If we are correct in attributing the events to capture by carbon, reaction (1), then the mass of the Y^* may be accurately determined. The measured average momentum of 171 $\pm$ 2 MeV/c corresponds to a Q-value of 11.9 $\pm$ 0.3 MeV. If boron is in its ground state, the mass of Y^* is 1404.7 $\pm$ 0.4 MeV. It has been assumed here that the atomic binding energy of the K-meson is 0.1 MeV, corresponding to capture from orbits with n=2 or 3, and that the K meson mass is 493.9 $\pm$ 0.2 MeV. The assumption of reaction (1) with boron in its ground state is supported by direct measurements of the invariant mass,

$M = \sqrt{(E_\Sigma + E_\pi)^2 - (\bar{p}_\Sigma + \bar{p}_\pi)^2}$ which gives for the 8 events in the peak in Fig. 4 a mean value M = 1403 $\pm$ 2 MeV.

The decay of the Y^* in our sample is consistent with a branching ratio equal to unity for the Σ^+ and Σ^- channels. It is also consistent with isotropic angular distribution in the C.M.S. More data are needed, however, to allow precise statements on these matters.

In the present experiment use has been made of some of the particular advantages of emulsion as a detector, namely its precision and high space resolution. It also seems as if the rich content of carbon (highest next to hydrogen) in the emulsion has been important. It should be remarked that the precision of measurement could be somewhat increased in a stack large enough to stop all pions. The sensitivity of the line position to energy changes is such that it should be possible to resolve lines corresponding to excited states in the residual nucleus and to

captures in oxygen and nitrogen in many cases. One possible reason for not clearly seeing evidence for other lines in the present experiment may be the low intensity of all reactions except the one leading to the ground state of boron, together with the fact that nuclear emulsions are rich in carbon.

In conclusion, we believe that the present measurements show clear evidence for a narrow momentum line at 171 $\pm$ 2 MeV/c in the $\Sigma\pi$ system when this is produced in the capture at rest of negative K mesons by light nuclei. The recoil of the residual nucleus has been observed to be strongly correlated with the line. An interpretation in terms of a Y^* particle with a mass of 1404.7 $\pm$ 0.4 MeV and a width of less than 1.4 MeV seems unavoidable. There are difficulties in reconciling the small width reported here with other experimental results on Y_0^*, if the particles appearing in the different experiments are identical. Full details of the present experiment and extensions of the work which is in progress will be reported in a forthcoming paper.

The permission to utilize the excellent K meson beam from the Lawrence Radiation Laboratory Bevatron is gratefully acknowledged. Thanks are due to our colleagues at the Institute for Theoretical Physics, University of Copenhagen, especially Mr E.Dahl-Jensen for the processing of the emulsions. We would like to express our thanks to prof. C.F.Powell for comments on the manuscript. The support of the Swedish Atomic Research Council is acknowledged as is also the free machinetime on the Facit EDB computer put at our disposal by the Swedish Board for Computing Machinery. The research reported in this document has been sponsored in part by: AIR FORCE OFFICE OF SCIENTIFIC RESEARCH, OAR, through the European Office, Aerospace Research, United States Air Force.

References

1) M.H. Alston, L.W. Alvarez, P. Eberhard, M.L. Good, W. Graziano, H.K. Ticho, S.G. Wojcicki Phys. Rev. Letters, 5, 520 (1960).

2) M.H. Alston, L.W. Alvarez, P. Eberhard, M.L. Good, W. Graziano, H.K. Ticho, S.G. Wojcicki Phys. Rev. Letters, 6, 698 (1961).

3) C.T. Coffin et.al, 1962 International Conference on High Energy Physics at CERN.

4) L. Bertanza et.al, 1962 International Conference on High Energy Physics at CERN.

5) M.H. Alston et.al, 1962 International Conference on High Energy Physics at CERN.

6) G. Alexander, G.R. Kalbfleisch, D.H. Miller, G.A. Smith, Phys. Rev. Letter 8, 447, 1962.

7) P. Bastien, O. Dahl, J.J. Murray, M. Watson, R.G. Ammar, P. Schlein, Proceedings of an International Conference on Instrumentation for High Energy Physics, Lawrence Radiation Laboratory, 1960.

8) Y. Eisenberg, G. Yekutieli, P. Abrahamsson, D. Kessler, Nuovo Cim 21, 563 (1961), and The Aix-en-Provence Conference Proceedings, vol. I, 389 (1961).

9) E.H.S. Burhop, The Aix-en-Provence Conference Proceedings, vol. I, 395 (1961).

10) S. Nilsson, Å. Frisk, Ark.f.fysik 14, 303 (1958).

11) H.H. Heckman, B.L. Perkins, W.G. Simon, F.M. Smith, W.H. Barkas, Phys. Rev. 117, 544 (1960).

12) H. Tyrén, private communication.

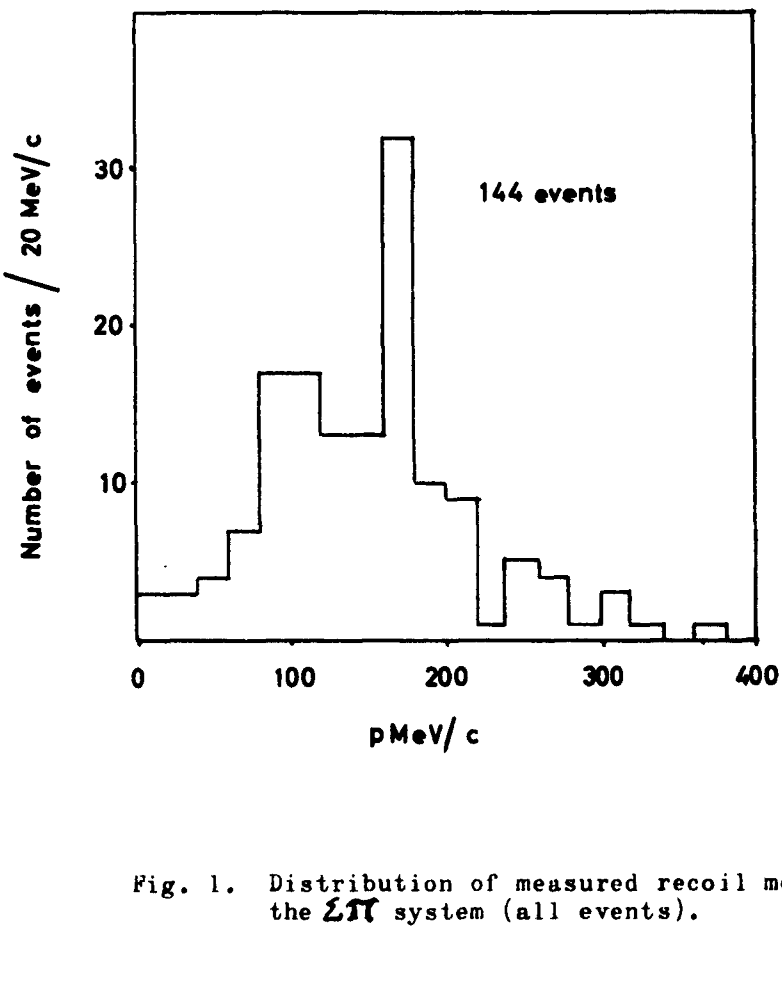


Fig. 1. Distribution of measured recoil momentum of the $\Sigma\pi$ system (all events).

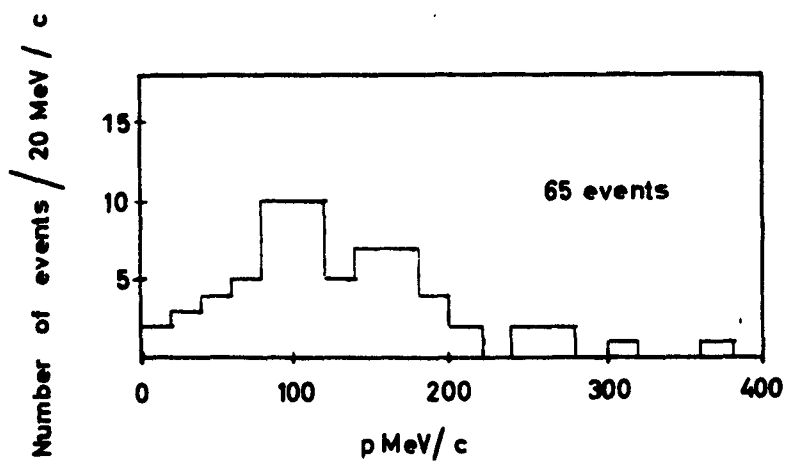


Fig. 2. Distribution of measured recoil momentum of the $\Sigma\pi$ system for events with no distinguishable track due to the recoiling nucleus.

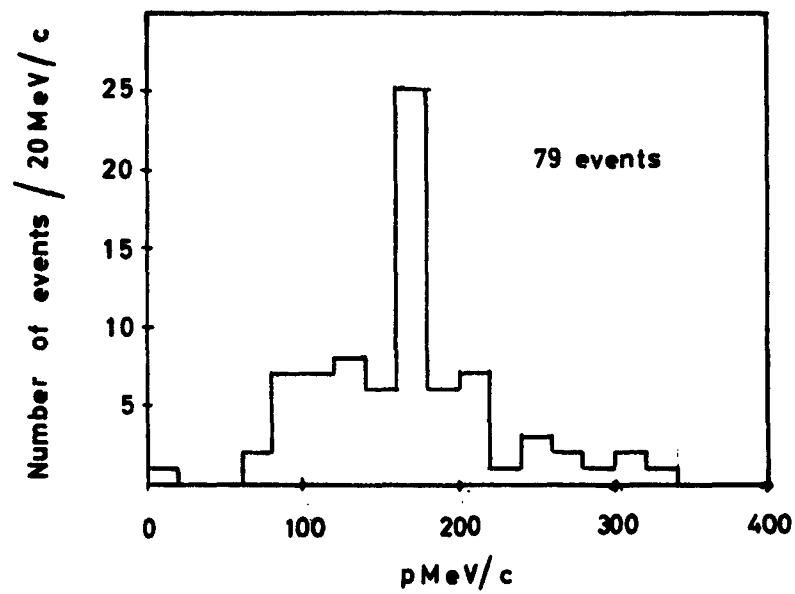


Fig. 3. Recoil momentum distribution for the sample which is enriched in events with a recoil track (< 5 μm).

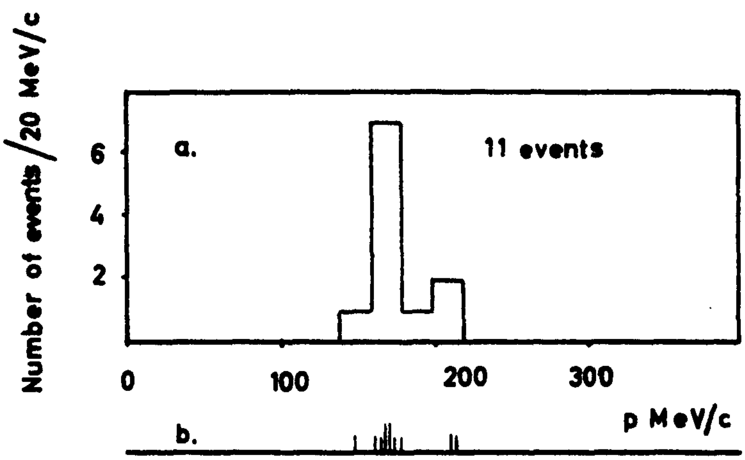


Fig. 4. Recoil momentum distribution for events with a clear short track due to the residual nucleus:
a) the events in 20 MeV/c bins
b) the measurements of individual recoil momenta.

3.2. Discussion

The research reported in the above paper will continue. The discovery reported needs confirmation in view of its importance for our understanding of the new short lived particles or resonances. Some confirmation has been obtained recently by S.White and C.Gilbert (Los Angeles and Livermore). The evidence for the effect is based on statistical significance arguments. It seems extremely unlikely that a 7 standard deviation peak in a smooth background distribution can occur. Furthermore, the peak is clearly correlated with the appearance of recoil tracks of such range as to be expected from the proposed reaction, $K^- + {}^{12}C \rightarrow Y^* + {}^{11}B$. Systematic effects have been considered but none has been found capable of producing the observed momentum line. The present work was based on an investigation of 6000 K meson stoppings in nuclear emulsions. A decision has been made to make new experiment in which 500000 negative K mesons will be stopped in nuclear emulsions. The experiment has been scheduled for a run at the CERN PS in January 1963. A new dark room for the devolopment of these emulsions is under construction. The best conditions for the experiment is being determined. Nuclear emulsions are well suited for this type of research; in fact no other detector has the required high space resolution and high precision. The sensitivity of our method is so great that we can resolve Y^* events coming from the three light nuclei, namely carbon, oxygen and nitrogen, and possibly also distinguish between cases where the residual nuclei are left in various states of excitation. At present the intensity is too low to achieve all this, the next experiment will provide enough data to make this feasible. If such effects are found, they will constitute convincing proofs of the properties of Y^* as now reported. Furthermore, higher precision in the data and information of the decay parameters of Y^* will be obtained. In order to handle the large amount of K mesons, a quick method to extract information is needed. We are investigating one possible, such method at present. In short, the method relies on the observation of the short recoil tracks associated with the Y^* events. By selecting $\Sigma\pi$ events associated with recoils the background is considerably reduced as is seen from the following figures. In our sample of 6000 K interactions, 144 was selected having a Σ and a pion in the final state. In this sample the Y^* line corresponds to about 13 percent. In the sample with recoils in a direction opposite

to the Y^* momentum the useful events amount to about 80 per cent.

4. Pion-electron scattering cross section.

4.1 Introduction

Pion electron scattering is an example of electromagnetic interaction. Theoretical formulae are since long developed discribing the scattering cross section for pointcharge particles. Experimental investigations of the cross section serve to test the underlying basic ideas of the theory. Deviations of experimental results from theoretical predictions, when not caused by experimental errors, serve to find new interactions or to establish that the assumptions made in deriving the theoretical formulae are not corresponding to reality.

In the case of particle-electron scattering no deviations have been found at low momentum transfers. This is a region, therefore, where theory may be trusted. At high momentum transfers a deviation towards lower cross sections may be interpreted in terms of an extended space structure of the particle. Investigations along this line has successfully been made only for protons and neutrons, the only two particles available readily as targets for an impinging electron beam. If one instead takes electrons as targets with the particle under investigation in an incoming beam, one can in principle perform the experiment for all types of particles. However, the high momentum transfers needed become kinematically possible only for extremely high energies of the particle beam.

The present investigation is concerned with a determination of the pion electron scattering cross section with 16 GeV negative pions incident on a liquid hydrogen bubble chamber, serving as electron target. Absolute differential cross sections have been determined for energy transfers between 30 MeV and the maximum possible value of 7300 MeV (lab. energies). We find an integrated cross section in this range of energy transfer of $\sigma = 8.34 \pm 0.28$ mb. This value is in agreement with Bhabhas theoretical point charge formula. A slight deviation of the differential cross section at high momentum tranfers has been evaluated to correspond to a radius of the pion between 1 and 2 fm (10^{-15}m) with errors such as not to exclude a zero radius.

4.2. Experiment

The beam was a 16 GeV/c negative pion beam at the CERN proton synchrotron. The purity of the beam was 89 % pions and 11 % muons. The experiment is part of two runs of the CERN 30 cm liquid hydrogen bubble chamber. A total number of 24124 pictures, exposed in March and October 1960, were scanned for pion electron collisions, sometimes called delta ray productions. The film was scanned twice in order to increase the efficiency of finding events and also in order to determine the efficiency as a function of the energy, T, transferred to the electron. The energy was determined for all events where the electron track had a radius larger or equal to 6 cm on the scanning table. The lower limit corresponds to an electron energy in the region 26 - 29 MeV, depending on the position of the track in the chamber.

The chamber was situated in a magnetic field, B, such that the mean value along a track is 14.57 kGauss, constant to within 1 % over the relevant volume of the chamber. From the measured electron track radius, R, and dip angle, λ, the electron momentum, p, is obtained according to the formula

$$p = \frac{0.3 \cdot B \cdot R}{\cos \lambda} = 4.36 \cdot \frac{R}{\cos\lambda}$$

In calculating the radius, R, the measured radius was corrected for the magnification which varies with depth in the chamber and also for position and orientation relative to the camera. All radii were measured with templates on the scanning table.

The number of delta rays with an energy larger than an arbitrary energy T is denoted $N(>T)$. The integrated cross section is obtained from the relation

$$\sigma(>T) = \frac{N(>T)}{N_e \cdot L}$$

where N_e is the number of electrons per unit volume, depending on the hydrogen density, and L is the total scanned pion track length. The latter is obtained from the total number of pictures, the mean number of tracks per picture and the mean length of a track in the fiducial volume of the chamber. In computing the latter account was taken of the form of the fidu-

cial volume and the distribution of the incoming beam over the entrance area. A correction was applied for the shortening of some pion tracks due to interactions with protons. This correction is of the order of 1%.

No measurement of the scattering angle was made. Therefore no kinematical identification of the events was made. Consequently not only elastic but also inelastic events are noted at the scanning as well as small angle pion proton two prong stars and deltas produced by incoming tracks not being beam tracks. However, the pion proton and the out-of--beam interactions have been removed by careful investigation of the events and an application of the following criteria:

(1) no visible change of direction of the assumed pion
(2) both outgoing tracks negative
(3) the incoming track defined in direction within 0.3 deg.

In addition, the volume of the chamber in which the apex of a noted event must lie is chosen considerably smaller than the total chamber volume for the following three reasons:

(1) to make sure that the interaction has really taken place in the chamber.
(2) to get enough track length to make possible measurements of the largest. radii of curvature.
(3) to eliminate events produced by tracks not belonging to the main beam.

Corrections for scanning efficiency and muon contamination.

By scanning all pictures twice and compairing the results one can determine the scanning efficiency. We have done this for various electron momenta. Let N_{1+2} be the number of events found in the two scannings, N_{12} be the number of events present in both scannings, N_1 and N_2 the number of events found in the first and second scanning, respectively.

The efficiency, ε, is given by: $\varepsilon = \frac{N_{1+2} \cdot N_{12}}{N_1 \cdot N_2}$

As may be expected the efficiency decreases with increasing radius of curvature of the track.

Fig.1 shows the efficiency as a function of the electron momentum, p.

The muon contamination of the beam has been determined by the CERN group to be 11%. The corrected number of delta rays, N_{corr}, to be used in the cross section calculation is obtained from the relation

$$N_{corr} = \frac{N}{1 + b\left(\frac{\sigma_\mu}{\sigma_\pi} - 1\right)}$$

where b is the fraction of the beam which is muon. For this correction the theoretical cross sections, σ_μ and σ_π, may be used. Table I summarizes the measurements.

TABLE I

Number of observed pion electron collisions as a function of lower limit of energy transferred to the electron, T_e.

T_e MeV	N_{uncorr}	N_{corr}
30	1083	1089
40	826	832,0
50	639	644,4
65	493	497,8
80	399	403,4
100	319	322,8
130	226	229,0
170	174	176,5
220	130	132,0
300	92	93,48
400	60	61,00
500	40	40,66
650	28	28,45
800	18	18,27
1000	16	16,21
1300	10	10,09
1700	5	5,017
2200	2	
3000	1	
4000	1	

One event corresponds to 7.66×10^{-3} mb

4.3. Results and comparison with theory

The differential cross sections determined in the above manner are shown in Fig. 2. The integrated cross sections are shown in Fig 3 as a function of the energy tranferred, T. For T = 30 MeV we obtain

$$\sigma(T > 30\ \mathrm{MeV}) = 8.34 \pm 0.28\ \mathrm{mb}$$

The corresponding theoretical value for a point charge pion is 8.271 mb. As the low momentum transfers dominate this cross section no detectable deviation due to an extended structure of the pion is expected. Experiment and theory agree satisfactory at this point.

The full drawn lines in Fig. 2 and Fig. 3 are theoretical curves for point charge scattering, i.e. the formfactor F is set equal to 1. The theoretical formula is given by Bhabha(1) and by Salecker(2) and is

$$\frac{d\sigma}{dT} = 2\pi\, r_e^{\,2}\, m_e \left(\frac{\gamma^2}{\gamma^2 - 1} - \frac{T}{T_{max}} + \frac{m_e T}{2p_\pi^2}\right) \frac{1}{T^2}\; F^2\,(q^2)$$

where the symbols are

$\frac{d\sigma}{dT}$ pion electron diff. cross section

T transferred energy to the electron

Tmax maximum energy transfer (is 7300 MeV in the present experiment)

γ the lorentz factor of the incident pion

p_π the lab. momentum of - " - - " -

q the transferred invariant momentum, given by $q^2 = 2 m_e T / \hbar^2 c^2$

r_e, m_e classical radius and mass of the electron

4.4. Discussion and form factor of the pion

The agreement between our experimental results and the theory for point charge scattering is rather good. There is a slight tendency to get smaller cross sections at high momentum transfers, an effect expected if the pion form factor is less than unity. However, the statistical accuracy is not good enough to exclude the possibility of having the form factor equal to unity in the region of interest here, which corresponds to transferred momenta squared up to $q^2_{max} = 0.192\ \mathrm{fm}^{-2}$. This is a rather low

value in spite of the fact that the pion beam momentum was as high as 16000 MeV/c. The experiment corresponds to a situation where electrons of 57 MeV energy impinge on pions at rest. An attempt to determine the radius of the pion by expanding the F^2 in a power series will be made only after the statistics has been at least doubled. At present the available film is practially exhausted by our experiment and a similar one at Aachen (Germany). The results of the two parts of the experiment will be presented in a joint paper (Aachen and Stockholm) now in preparation.

References

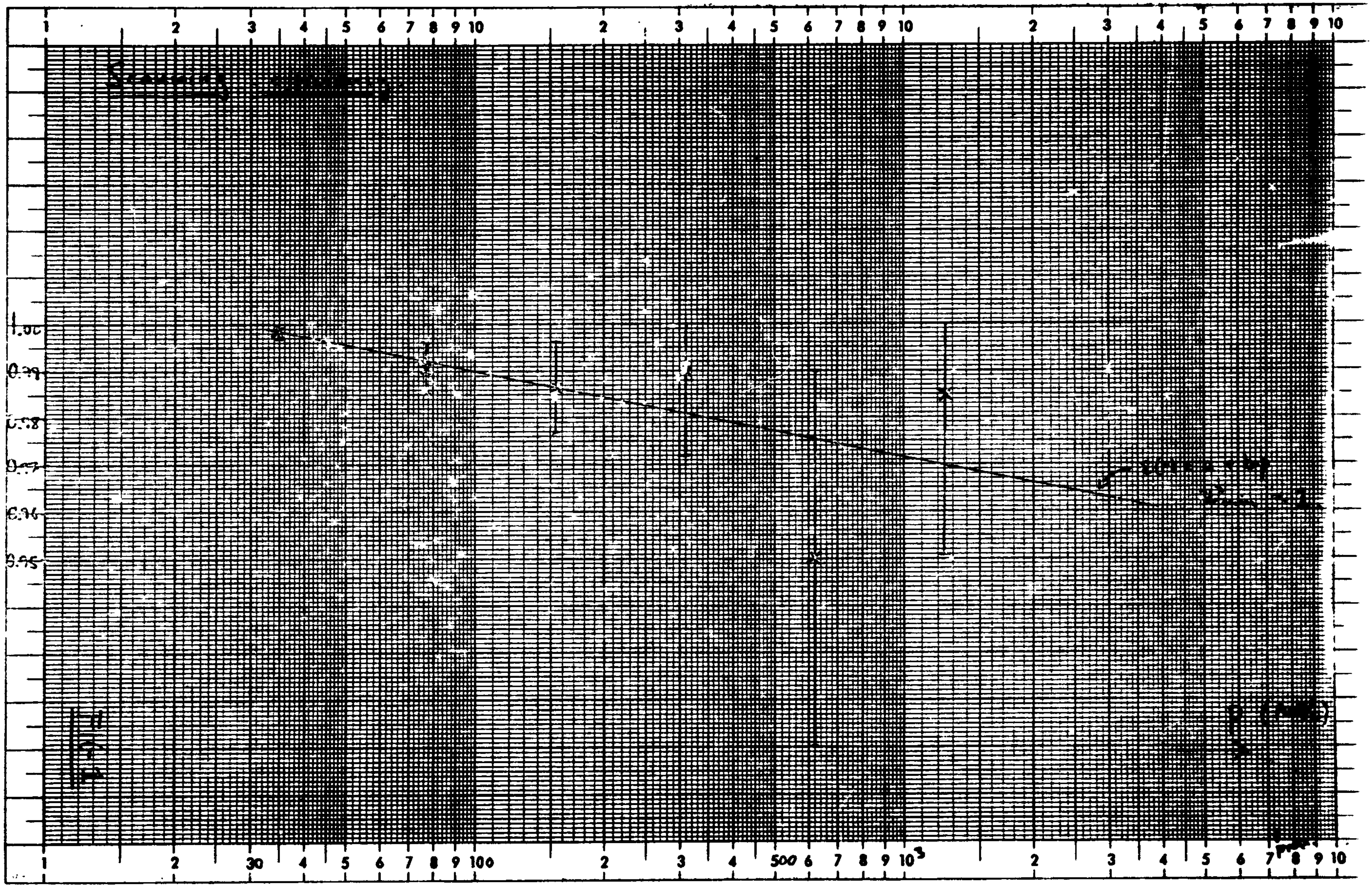
1. H.Bhabha, Proc, Roy. Soc 164, 257 (1938)
2. Salecker, Zeitsch, f. Nat. Forsch. 15 a, 1023 (1960)

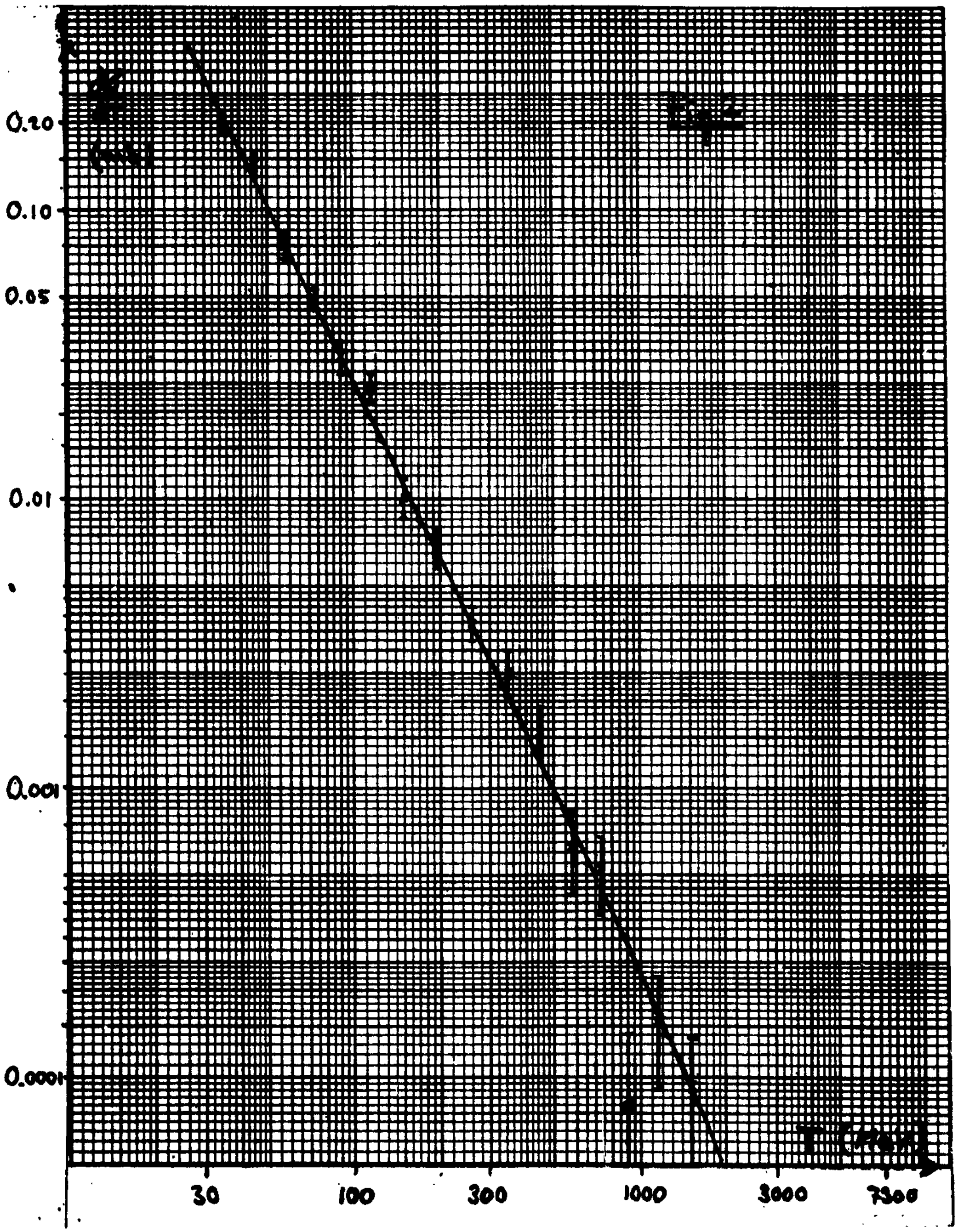
Figure captions.

Fig. 1. Scanning officiency $\mathcal{E}$ as a function of electron momentum p(in MeV/c). Full drawn curve represents the least-squares-fit of the function $\mathcal{E} = a + b\ln p$

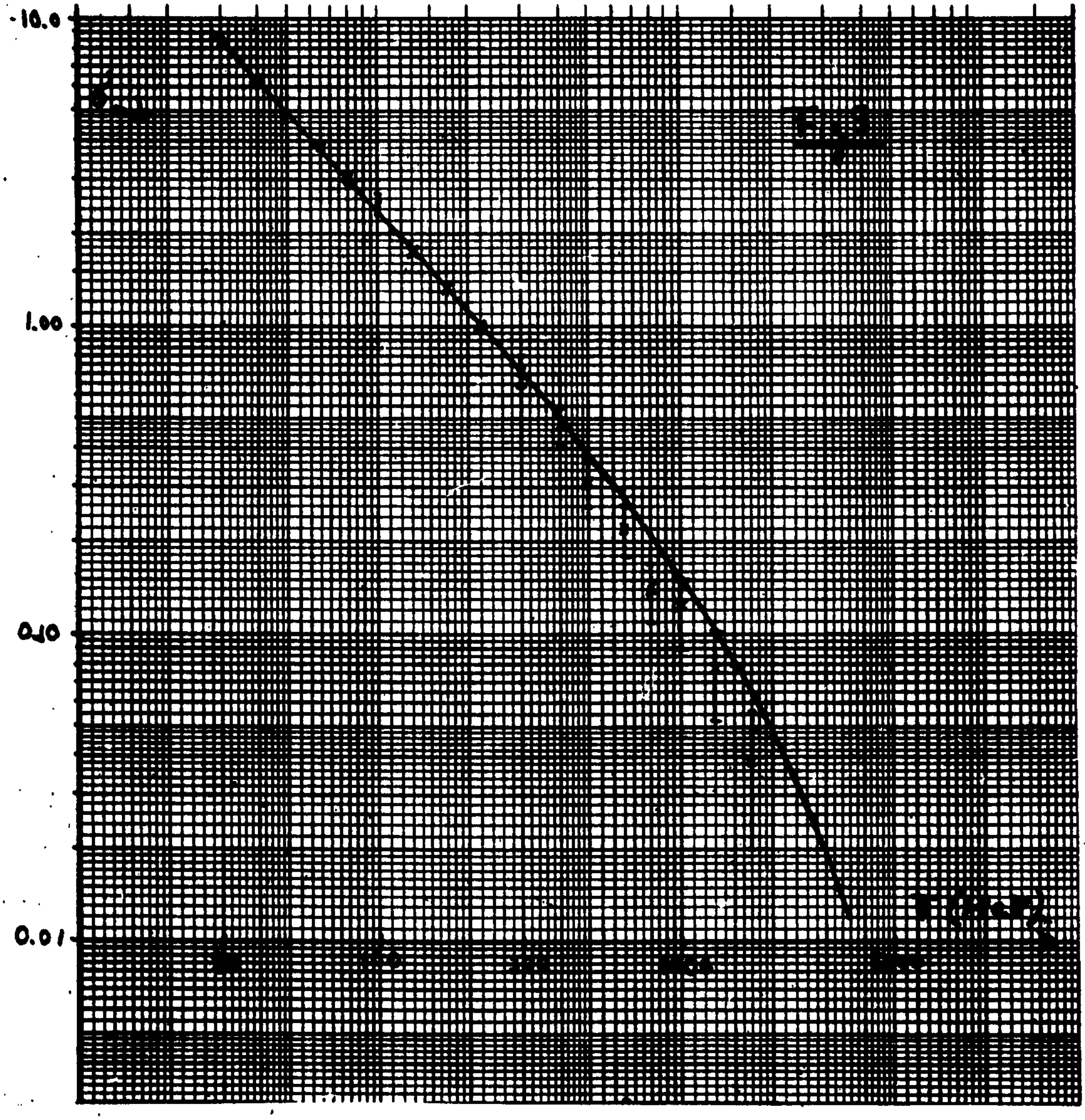
Fig. 2. Absolute differential cross section. Full drawn curve is the theoretical cross section for point charge pion.

Fig. 3. Integrated cross section as a function of the lower integration limit. Full drawn curve is the theoretical cross section for point charge pion.


1.00
0.99
0.98
0.97
0.96
0.95
30
100
500
10³



0.20
0.10
0.05
0.01
0.001
0.0001
30
100
300
1000
3000
7300


10.0
1.00
0.10
0.01

INST OF PHYSICS
UNIVERSITY
STOCKHOLM
31 OCT 1962

EOAR 61 - 67
TR
PHYSICS

HIGH ENERGY NUCLEAR PHYSICS

A. G. EKSPONG

ABSTRACT: Discovery of Y^* hyperon at 1405 MeV with narrow massdistribution, $\Gamma < 1.4$ MeV.
Antiprotons of 1.3 GeV energy invest. interaction with emulsion nuclei; average pion multiplicity is 5.0 and average energy 430 MeV. Also interactions of 2 GeV pions.
Pion electron collisions at 16 GeV pion energy in the region of transferred energy 30 MeV - 7300 MeV.

INST OF PHYSICS
UNIVERSITY
STOCKHOLM
31 OCT 1962

EOAR 61 - 67
TR
PHYSICS

HIGH ENERGY NUCLEAR PHYSICS

A. G. EKSPONG

ABSTRACT: Discovery of Y^* hyperon at 1405 MeV with narrow massdistribution, $\Gamma < 1.4$ MeV.
Antiprotons of 1.3 GeV energy invest. interaction with emulsion nuclei; average pion multiplicity is 5.0 and average energy 430 MeV. Also interactions of 2 GeV pions.
Pion electron collisions at 16 GeV pion energy in the region of transferred energy 30 MeV - 7300 MeV.

INST OF PHYSICS
UNIVERSITY
STOCKHOLM
31 OCT 1962

EOAR 61 - 67
TR
PHYSICS

HIGH ENERGY NUCLEAR PHYSICS

A. G. EKSPONG

ABSTRACT: Discovery of Y^* hyperon at 1405 MeV with narrow massdistribution, $\Gamma < 1.4$ MeV.
Antiprotons of 1.3 GeV energy invest. interaction with emulsion nuclei; average pion multiplicity is 5.0 and average energy 430 MeV. Also interactions of 2 GeV pions.
Pion electron collisions at 16 GeV pion energy in the region of transferred energy 30 MeV - 7300 MeV.

INST OF PHYSICS
UNIVERSITY
STOCKHOLM
31 OCT 1962

EOAR 61 - 67
TR
PHYSICS

HIGH ENERGY NUCLEAR PHYSICS

A. G. EKSPONG

ABSTRACT: Discovery of Y^* hyperon at 1405 MeV with narrow massdistribution, $\Gamma < 1.4$ MeV.
Antiprotons of 1.3 GeV energy invest. interaction with emulsion nuclei; average pion multiplicity is 5.0 and average energy 430 MeV. Also interactions of 2 GeV pions.
Pion electron collisions at 16 GeV pion energy in the region of transferred energy 30 MeV - 7300 MeV.